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ORIGINAL ARTICLE

Training of attention functions in children with attention deficit hyperactivity disorder

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Abstract Pharmacological treatment of children with ADHD has been shown to be successful; however, medication may not normalize attention functions. The present study was based on a neuropsychological model of attention and assessed the effect of an attention training program on attentional functioning of children with ADHD. Thirty-two children with ADHD and 16 healthy children participated in the study. Children with ADHD were randomly assigned to one of the two conditions, i.e., an attention training program which trained aspects of vigilance, selective attention and divided attention, or a visual perception training which trained perceptual skills, such as perception of figure and ground, form constancy and position in space. The training programs were applied in individual sessions, twice a week, for a period of four consecutive weeks. Healthy children did not receive any training. Alertness, vigilance, selective attention, divided attention, and flexibility were examined prior to and following the interventions. Children with ADHD were assessed and trained while on ADHD medications. Data analysis revealed that the attention training used in the present study led to significant improvements of various aspects of attention, including vigilance, divided attention, and flexibility, while the visual perception training had no specific effects. The findings indicate that attention training programs have the potential to facilitate attentional functioning in children with ADHD treated with ADHD drugs.

Keywords ADHD · Children · Attention training · Non-pharmacological treatment

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Introduction

Inattention is one of the core symptoms of attention deficit hyperactivity disorder (ADHD). With regard to the attention deficit, parents and teachers often report that children with ADHD have difficulties in concentrating, in paying attention to details, and in sustaining attention for a prolonged period of time. Furthermore, children with ADHD are easily distracted and have problems in planning, organizing, and finishing assigned tasks (Barkley 2006). While performing tasks, they also need more supervision and redirection than healthy children. These reports are well supported by the results of well controlled, laboratory-based studies that showed significant impairments of children with ADHD in neuropsychological measures of attention (Borger et al. 1999; Lockwood et al. 2001; Perugini et al. 2000). Pharmacological treatment using stimulant medication has consistently been found to improve the attention deficit in children with ADHD. For example, Tucha et al. (2006c) applied a multi-dimensional model of attention and found that children with ADHD suffer from a global deficit of attention comprising impairments of vigilance, selective attention, focused attention, divided attention, and shifting. Pharmacological treatment using individually tailored and clinically appropriate doses of methylphenidate resulted in a significant improvement of all impaired functions of attention (Tucha et al. 2006b). However, although beneficial effects of the medication have been observed, children with ADHD did not reach an undisturbed level of attention. They still displayed significant deficits in a number of components of attention, including aspects of selective attention, divided attention, vigilance, and shifting. These findings clearly indicate a need for additional treatment of the attention deficit in children with ADHD. This is supported by the findings of Gualtieri and Johnson (2008) who also demonstrated that even successful pharmacological treatment does not normalize cognitive functioning in children with ADHD.

Although research data indicate that pharmacological treatment is effective alone and appears to be the most effective part of comprehensive multi-modal treatment (Greenhill 1992; Pelham et al. 1992; Wilens and Biederman 1992), other approaches may add to the success of medication. Moreover, non-pharmacological treatment should be included in the management of ADHD because not all children might tolerate ADHD medications and some parents might be reluctant to have their children treated with pharmacological agents. One approach to the supportive treatment of the attention deficits in medicated children with ADHD could be the use of attention training programs such as those developed for children and adults with acquired brain lesions. Although these training programs have been available for a considerable time, only a limited number of studies have examined their usefulness in the treatment of attention deficits in patients with ADHD.

For example, Kerns et al. (1999) examined the effectiveness of an attention training program ("Pay Attention!" by Thomson et al. 1994) in children with ADHD. Measures of lower levels of attention, including sustained and selective attention, and of higher levels of attention, including alternating and divided attention, were assessed prior to and following the attention training. The findings suggest that the direct training of attention had a beneficial effect on both lower and higher levels of attention. In general, these effects of the "Pay Attention!" program have recently been replicated in a study by Tamm et al. (2010). These authors included 23 children with ADHD of whom 7 children completed all training sessions. However, the value of the results is limited because a control group was lacking. Therefore, the impact of possible practice effects is difficult to estimate. Semrud-Clikeman et al. (1999) made comparisons among children with ADHD who received an attention training and two control groups who received no training, i.e., an ADHD control group and a group of healthy children. The training focused on sustained attention and problem-solving skills and consisted of tasks from the attention process training (APT) developed by Sohlberg and Mateer (1989). Data analysis revealed significant interaction effects indicating considerable improvements in attentional performance of the children with ADHD who received the attention training.

The findings of available studies (Kerns et al. 1999; Semrud-Clikeman et al. 1999; Tamm et al. 2010) indicate that improvement of attentional functioning in children with ADHD can be promoted through direct training of attention. On the basis of these findings, the present study aims to evaluate the effectiveness of a deficit-specific approach to the treatment of attention deficits of children with ADHD. Previous research demonstrated that specific deficits of attention require specific training by using specific tasks designed to address these deficits (Sturm and Willmes 1991; Sturm et al. 1997). Therefore, various components of attention were considered both in the selection of the test procedures and in the selection of procedures for the training of attention functions. These selections were made on the basis of the model delineated by Van Zomeren and Brouwer (1994). This model is based on the multi-component model of Posner and colleagues (Posner and Boies 1971; Posner and Rafal 1987), the distinction between selectivity and intensity of attention made by Kahneman (1973) and the concept of a supervisory attentional control as devised by Shallice (1982). It contains the concepts of alertness (tonic and phasic alertness), vigilance, selective attention, divided attention, and flexibility (Van Zomeren and Brouwer 1994). For the training of attention function, a commercially available program (AixTent; Sturm et al. 2001) was used. It allows the treatment of disturbances of alertness, vigilance, selective attention, and divided attention which all represent functions of attention that have been found to be impaired in children with ADHD (Lange et al. 2007; Tucha et al. 2006b, c, 2009). Based on previous literature, we hypothesized that children with ADHD would suffer from deficits in various aspects of attention and that a training of multiple dimensions of attention would result in significant improvements of the attentional functioning of children with ADHD.

Methods

Participants

Thirty-two children with ADHD according to DSM-IV criteria as diagnosed by child and adolescent psychiatrists participated in the present study. Children were recruited via a child and youth welfare service (Kinderzentrum St. Vincent, Regensburg, Germany), public announcements, and word-of-mouth. Twenty-six children met diagnostic criteria for an additional comorbid psychiatric condition (attachment disorders: $n = 9$; specific reading and/or spelling disorders: $n = 8$; adjustment disorders: $n = 4$; specific developmental disorders of speech and language: $n = 2$; specific developmental disorder of motor function: $n = 2$; and Asperger's syndrome: $n = 1$). Since psychiatric comorbidities are common in children with ADHD (Kadesjo and Gillberg 2001; Szatmari et al. 1989), psychiatric comorbidity was not a reason for exclusion. At the time of the study, all children with ADHD were being treated with ADHD medications (stimulants: $n = 30$; selective noradrenaline re-uptake inhibitor: $n = 2$). Children with ADHD continued taking their medication throughout the intervention. Intellectual abilities (IQ) were measured using the Wechsler Intelligence Scale for Children (Wechsler 1991) or the Kaufman Assessment Battery for Children (Kaufman and Kaufman 1983). Children with ADHD were randomly assigned to one of the two groups. In one group ("attention training group"), children with ADHD received a specific training of attention functions (AixTent; Sturm et al. 2001). Children in the other group ("perception training group") participated in a training of visual perception (Frostig Developmental Program of Visual Perception; Frostig et al. 1972). During the assignment, it was assured that the groups did not differ regarding the number of girls and boys. The interventionists who trained the children were aware of the children's clinical status.

Furthermore, 16 healthy children were assessed. Healthy children were selected from a pool of participants who voluntarily participated in the neuropsychological assessment (recruited via public announcements and word-of-mouth). Selection was random, except that children of the same age range were selected and that children were matched with the ADHD groups in regard to the proportion of boys and girls. None of these children had any history of neurological or psychiatric disease or displayed signs of ADHD or learning disability. No healthy participant was taking medication known to affect the central nervous system at the time of the study. The intellectual abilities (IQ) of healthy children were assessed using the vocabulary subtests of the CFT 20 (Weiß 1998), a standard short measure for estimating intellectual abilities. Characteristics of groups are summarized in Table 1. Statistical comparison among groups indicated that the three groups did not differ with regard to sex, age ($\chi^2 = 0.06$, $df = 2$, $P = 0.972$), or IQ ($\chi^2 = 3.50$, $df = 2$, $P = 0.173$). All parents were informed of the aims and nature of the study and gave written consent prior to the start of the study.

Measures

For the assessment of attentional functioning of participants, six computerized tests of attention (Zimmermann and Fimm 1993, 2002) were applied measuring aspects of tonic and phasic alertness, selective attention, vigilance, divided attention, and flexibility (Table 2). The tests were of low complexity and, therefore, well suited for the assessment of children. Furthermore, previous research had demonstrated that these measures are sensitive to the impairments of children with ADHD (Tucha et al. 2006b, c, 2009). Children with ADHD were examined prior to and following an intervention, while healthy children were examined only once.

Tonic and phasic alertness

In the alertness tasks, participants were asked to respond by pressing a button when a visual stimulus appeared on a computer screen. In the first 20 trials, the stimulus appeared on the screen without prior warning (tonic alertness task), while during the second 20 trials, a warning tone preceded the appearance of the stimulus (phasic alertness task). The time span between the warning tone and the appearance of the stimulus was random.

Vigilance

In the vigilance task, a structure consisting of two rectangles was presented in the center of the computer screen. One rectangle was situated on top of the other. These rectangles were alternately filled with a pattern (stimulus)

Table 1 Characteristics of healthy participants and children with ADHD (means ± SEM)

	Healthy children	Children with ADHD	
		Attention training group	Perception training group
N	16	16	16
Sex (female/male)	5/11	5/11	5/11
Age (in years)	10.7 ± 0.4	10.8 ± 0.4	11.0 ± 0.6
Intellectual functions (IQ)	103.6 ± 1.3	101.6 ± 2.9	99.7 ± 2.6

Table 2 Neuropsychological test battery

Function	Test measure[a]	Test variables
Tonic alertness	Alertness, first 20 trials	Mean reaction time
		Number of omission errors
Phasic alertness	Alertness, second 20 trials	Mean reaction time
		Number of omission errors
Vigilance	Vigilance, 600 trials, 15 min	Mean reaction time
		Number of omission errors
		Number of commission errors
Selective attention	Visual scanning, 50 trials	Mean reaction time
		Number of omission errors
		Number of commission errors
Divided attention	Divided attention, 100 trials	Mean reaction time
		Number of omission errors
		Number of commission errors
Flexibility	Alternating flexibility, 100 trials	Mean reaction time
		Number of commission errors

[a] From the test battery for attentional performance (TAP; Zimmermann and Fimm 1993)

for 500 ms with an interstimulus interval of 1,000 ms. The duration of the test was 15 min. A total of 600 stimuli (changes of pattern location) was presented. The participants were requested to press the response button as quickly as possible when no change of the pattern location occurred. The target rate (i.e., no change of pattern location) was about one target stimulus per minute for a total of about 18 targets. The time intervals between target stimuli were irregular.

Divided attention

The divided attention task required participants to concentrate simultaneously on a visual and an acoustic task presented by a computer. In the visual task, a series of matrices were presented in the center of the computer screen. Each matrix consisting of a regular array of sixteen dots and crosses (4 × 4) was displayed for 2,000 ms. The participant was asked to press the response button as quickly as possible whenever the crosses formed the corners of a square (visual target). In the acoustic task, the participant was requested to listen to a continuous sequence of alternating high and low sounds and to press the response button as quickly as possible when irregularities of the sequence occurred (acoustic target).

Selective attention

In the visual scanning task, a series of 5 × 5 matrices were presented in the center of the computer screen. Each matrix consisted of a regular pattern of 25 squares each of which had an opening on one side (top, bottom, left, or right side). A square with an opening at the top was defined as a critical stimulus. The critical stimulus occurred only once in a matrix and was randomly distributed across the matrix. The participant was asked to press the left response button as quickly as possible whenever a matrix contained a critical stimulus (critical trials) or to press the right response button if the critical stimulus was not present (noncritical trials).

Flexibility

The alternating flexibility task required the participant to place each hand on a separate response button while viewing a computer screen on which a letter and a digit number were displayed simultaneously. The participant was instructed to respond by alternately pressing the button that was on the same side of the screen as the letter and then pressing the button that was on the same side of the screen as the number. After each response, a new letter and number appeared, randomly assigned to either side of the screen.

Intervention

Children with ADHD of both groups (attention training group, perception training group) received individual training sessions, twice a week, for a period of four consecutive weeks (8 training sessions in total). Each training session took about 1 h. Forty-five minutes were attributed to the specific training, while the remaining time was used for welcoming the child, starting the computer and training procedures, making the child comfortable with the situation, etc. This time schedule was chosen in order to guarantee regular attendance of participants, which is often a problem in this kind of study (see Tamm et al. 2010). Furthermore, a training like this could easily be incorporated in the treatment provided by health services and hospitals, e.g., during the adjustment of pharmacological treatment. Healthy children did not receive any training.

Attention training

AixTent is a computerized training program, which was developed on the basis of results of clinical studies indicating (1) that different aspects of attention can be impaired selectively and (2) that unspecific training programs are not very effective in the training of different components of attention (Sturm and Willmes 1991; Sturm et al. 2001). The program comprises training procedures that allow the specific training of four different components of attention, namely alertness, vigilance, selective, and divided attention. The training procedures are designed like simple computer games that are adaptive with regard to their difficulty level. This means that according to the performance of a participant, the program steps automatically through nine difficulty levels. The difficulty level increases when a participant makes 5 or less errors within 48 responses. If the participant makes more than 16 errors, the program automatically returns to the previous difficulty level (Sturm et al. 2001). In the present study, the children with ADHD assigned to this intervention performed trainings of vigilance, selective attention, and divided attention. Children were trained on all of these functions since comparison of children's performances with normative data of healthy children indicated that all children with ADHD showed impairments in at least two of these functions. Each of these three attention functions was trained for 15 min during each session. The following training procedures of Aixtent were used in the present study: "FLIESSBAND" ("Conveyor belt") as a training for vigilance, "FOTO" ("Photo") as a training for selective attention, and "COCKPIT" ("Cockpit") as a training for divided attention. The efficacy of the AixTent program has been demonstrated in patients with unilateral brain lesions of vascular etiology (Sturm et al. 1994, 2001). A training of alertness was not performed, since previous studies demonstrated that both children and adults with ADHD do not differ from healthy participants in either tonic or phasic alertness (Tucha et al. 2006a, b, c, 2008, 2009). A training of flexibility (shifting of the focus of attention) was not included, since an appropriate training procedure with proven effectiveness is not yet available.

Visual perception training

The German version of the Frostig Developmental Program of Visual Perception (Frostig et al. 1972; German version by Reinartz and Reinartz 1974) was used as an unspecific training program. This program was developed for the training of elementary school students with impaired visual-perceptual abilities. The training comprises tasks exercising skills in five areas: eye-motor coordination, figure-ground perception, perception of form constancy, perception of position in space, and spatial relationships. The training materials consist of colored pencils and various working sheets. The difficulty of working sheets increases over the course of the training. While in the earlier stages of the training, simple drawing tasks have to be performed (e.g., drawing of straight or curved lines between boundaries), complex perception tasks (e.g., discrimination between figures in an identical position and those in a reversed or rotated position) have to be accomplished in the later stages of the training. All children received the same sequence of working sheets. Children completed all working sheets of the same level of difficulty across the five areas before moving on to the next higher level of difficulty. At the beginning of each subsequent session, children continued with the working sheet that followed the sheet they had completed last in the previous session.

Statistical analysis

Due to the small sample sizes of groups, statistical analysis was performed using nonparametric tests. While comparisons among groups were performed using Kruskal–Wallis and Mann–Whitney–U tests, Wilcoxon tests were used to compare the performance of children with ADHD before and following the interventions (attention training, visual perception training). Furthermore, ipsative scores were calculated for children with ADHD and compared between ADHD groups by using Mann–Whitney–U tests. Ipsative scores were calculated by subtracting the performances of children with ADHD in the assessment following the interventions (post-assessment) from the test results of children in the assessment performed prior to intervention (pre-assessment). These ipsative scores represent the change from pre- to post-assessment and are therefore measures of efficacy of the two interventions. An alpha level of 0.05 was applied for statistical analysis. All statistical analyses were carried out using SPSS 16.0 for Windows. Furthermore, effect sizes were computed. Following Cohen's guidelines for interpreting effect sizes (Cohen 1988), negligible effects ($d < 0.20$), small effects ($d = 0.20$), medium effects ($d = 0.50$), and large effects ($d = 0.8$) were distinguished.

Results

Comparisons among groups prior to intervention (attention training, visual perception training) and the healthy control group

Alertness

Statistical comparison among groups using Kruskal–Wallis tests revealed no significant differences in either the tonic alertness task (reaction time: $\chi^2 = 0.31$, $df = 2$, $P = 0.857$; number of omission errors: $\chi^2 = 2.00$, $df = 2$, $P = 0.368$) or the phasic alertness task (reaction time: $\chi^2 = 1.91$, $df = 2$, $P = 0.385$; number of omission errors: $\chi^2 = 2.09$, $df = 2$, $P = 0.352$). The results are summarized in Table 3.

Vigilance

Significant differences among groups were found in both the number of omission errors ($\chi^2 = 11.99$, $df = 2$, $P = 0.002$) and commission errors ($\chi^2 = 7.76$, $df = 2$, $P = 0.021$). Groups did not differ with regard to reaction time ($\chi^2 = 2.60$, $df = 2$, $P = 0.272$). Subsequent post hoc analysis using Mann–Whitney–*U* tests indicated that both groups of children with ADHD made significantly more omission errors (attention training group: $Z = -2.60$, $P = 0.008$; perception training group: $Z = -3.30$, $P = 0.001$) and commission errors (attention training group: $Z = -2.09$, $P = 0.039$; perception training group: $Z = -2.71$, $P = 0.006$) than healthy children. No differences were observed between the two ADHD groups (number of omission errors: $Z = -0.47$, $P = 0.642$; number of commission errors: $Z = -0.02$, $P = 0.985$).

Selective attention

While a significant difference was found among groups in the number of omission errors ($\chi^2 = 8.47$, $df = 2$, $P = 0.014$), groups did not differ concerning reaction time ($\chi^2 = 4.09$, $df = 2$, $P = 0.129$) and the number of commission errors ($\chi^2 = 2.62$, $df = 2$, $P = 0.269$). Post hoc

Table 3 Test performances of healthy children and children with ADHD prior to and following intervention (means ± SEM)

	Healthy children	Children with ADHD			
		Attention training group		Perception training group	
		Prior to training	Following training	Prior to training	Following training
Tonic alertness					
Reaction time (ms)	268.5 ± 9.6	273.5 ± 14.9	284.0 ± 20.3	275.1 ± 12.6	289.0 ± 14.4
Number of omission errors	0.0 ± 0.0	0.06 ± 0.06	0.13 ± 0.13	0.0 ± 0.0	0.0 ± 0.0
Phasic alertness					
Reaction time (ms)	252.0 ± 7.8	256.1 ± 17.3	259.7 ± 19.1	249.6 ± 8.9	255.9 ± 9.3
Number of omission errors	0.0 ± 0.0	0.13 ± 0.09	0.13 ± 0.09	0.06 ± 0.06	0.0 ± 0.0
Vigilance					
Reaction time (ms)	746.0 ± 16.5	720.0 ± 57.1	693.7 ± 43.7	745.5 ± 27.3	775.2 ± 25.8
Number of omission errors	3.13 ± 0.52	6.81 ± 1.08[a]	5.94 ± 1.18	7.06 ± 0.81[a]	8.13 ± 1.11[a]
Number of commission errors	3.50 ± 0.83	16.06 ± 6.26[a]	8.56 ± 3.15[b]	8.13 ± 1.92[a]	8.25 ± 1.57[a]
Selective attention					
Reaction time (ms)	3,546.8 ± 289.6	4,784.5 ± 522.4	4,654.9 ± 687.1	5,262.5 ± 701.0	4,482.3 ± 522.8
Number of omission errors	1.94 ± 0.45	4.81 ± 0.85[a]	3.31 ± 1.03	4.62 ± 0.90[a]	4.94 ± 0.76[a]
Number of commission errors	0.56 ± 0.16	1.75 ± 0.74	1.19 ± 0.39	0.44 ± 0.16	0.94 ± 0.28
Divided attention					
Reaction time (ms)	693.3 ± 13.7	714.7 ± 26.1	727.9 ± 26.7	669.1 ± 28.5	692.7 ± 19.0
Number of omission errors	1.00 ± 0.20	4.38 ± 0.90[a]	4.50 ± 1.38[a]	4.56 ± 0.83[a]	5.06 ± 0.68[a]
Number of commission errors	0.69 ± 0.18	2.94 ± 0.86[a]	0.63 ± 0.18[b]	2.38 ± 0.47[a]	2.38 ± 0.46[a,c]
Flexibility					
Reaction time (ms)	868.8 ± 43.1	1,005.6 ± 60.7	949.2 ± 81.5	1,046.8 ± 74.8	981.3 ± 74.0
Number of commission errors	2.56 ± 0.30	8.63 ± 2.11[a]	5.88 ± 1.13[a,b]	8.63 ± 2.09[a]	6.19 ± 1.08[a]

[a] $P \leq 0.05$ when compared with healthy children (Mann–Whitney–*U* test)

[b] $P \leq 0.05$ when compared with performance prior to training (Wilcoxon test)

[c] $P \leq 0.05$ when compared with the attention training group following intervention (Mann–Whitney–*U* test)

analysis showed that children with ADHD made more omission errors than healthy children (attention training group: $Z = -2.46$, $P = 0.014$; perception training group: $Z = -2.55$, $P = 0.011$). Children of the attention training group did not differ from children of the perception training group ($Z = -0.46$, $P = 0.669$).

Divided attention

Comparison of performance in the divided attention task among groups revealed a nonsignificant difference regarding reaction time ($\chi^2 = 1.49$, $df = 2$, $P = 0.475$) and significant differences in the number of omission errors ($\chi^2 = 13.47$, $df = 2$, $P = 0.001$) and commission errors ($\chi^2 = 10.62$, $df = 2$, $P = 0.005$). Children with ADHD displayed significantly more omission errors (attention training group: $Z = -3.29$, $P = 0.001$; perception training group: $Z = -3.07$, $P = 0.002$) and commission errors (attention training group: $Z = -2.90$, $P = 0.004$; perception training group: $Z = -2.77$, $P = 0.007$) than healthy children. No differences were found between the two ADHD groups (number of omission errors: $Z = -0.40$, $P = 0.696$; number of commission errors: $Z = -0.04$, $P = 0.985$).

Flexibility

Data analysis showed that groups differed in the alternating flexibility task with regard to the number of commission errors ($\chi^2 = 10.30$, $df = 2$, $P = 0.006$). While ADHD groups did not differ from each other ($Z = -0.11$, $P = 0.926$), both ADHD groups made significantly more commission errors than healthy children (attention training group: $Z = -2.97$, $P = 0.003$; perception training group: $Z = -2.58$, $P = 0.010$). The three groups did not differ in reaction time ($\chi^2 = 4.52$, $df = 2$, $P = 0.105$).

Comparisons between pre-training and post-training performance within ADHD groups

Perception training group

Statistical analysis using Wilcoxon tests revealed no significant differences in any of the test measures of attention used in the present study. Performance of children of the perception training group did not change from the pre-training to the post-training assessment in regard to tonic alertness (reaction time: $Z = -1.11$, $P = 0.266$; number of omission errors: $Z = 0.00$, $P = 1.000$), phasic alertness (reaction time: $Z = -0.85$, $P = 0.393$; number of omission errors: $Z = -1.00$, $P = 0.317$), vigilance (reaction time: $Z = -0.75$, $P = 0.453$; number of omission errors: $Z = -0.77$, $P = 0.441$; and number of commission errors: $Z = -0.28$, $P = 0.777$), selective attention (reaction time: $Z = -1.66$, $P = 0.098$; number of omission errors: $Z = -1.27$, $P = 0.205$; and number of commission errors: $Z = -1.73$, $P = 0.084$), divided attention (reaction time: $Z = -0.05$, $P = 0.959$; number of omission errors: $Z = -0.60$, $P = 0.547$; and number of commission errors: $Z = -0.08$, $P = 0.936$), and flexibility (reaction time: $Z = -0.88$, $P = 0.379$; number of commission errors: $Z = -0.88$, $P = 0.378$). The analysis of effect sizes revealed only negligible or small differences between assessments with the exception of medium effects between assessments in the reaction time and the number of commission errors in the visual scanning task (Table 4). The majority of small to medium effect sizes indicated slight decrements in functioning.

Attention training group

The attention training resulted in significant improvements of attentional functioning of children with ADHD. In comparison with their performance in the assessment prior to the training, children with ADHD produced significantly fewer commission errors in the vigilance task ($Z = -2.54$, $P = 0.011$), the divided attention task ($Z = -3.09$, $P = 0.002$), and the alternating flexibility task ($Z = -1.96$, $P = 0.050$) following the attention training. While the differences in divided attention and flexibility were of large size, a medium effect was found in vigilance. Furthermore, medium effects were found concerning the number of omission errors in the selective attention task and the reaction time in the alternating flexibility task, both indicating improvements of functioning. However, these differences did not reach significance (number of omission errors in the selective attention task: $Z = -1.61$, $P = 0.107$; reaction time in the alternating flexibility task: $Z = -1.50$, $P = 0.134$). The remaining differences in tonic alertness (reaction time: $Z = -0.78$, $P = 0.438$; number of omission errors: $Z = 0.45$, $P = 0.665$), phasic alertness (reaction time: $Z = -0.62$, $P = 0.535$; number of omission errors: $Z = 0.00$, $P = 1.000$), vigilance (reaction time: $Z = -0.36$, $P = 0.717$; number of omission errors: $Z = 0.74$, $P = 0.461$), selective attention (reaction time: $Z = -1.03$, $P = 0.301$; number of commission errors: $Z = 0.30$, $P = 0.762$), and divided attention (reaction time: $Z = -0.16$, $P = 0.877$; number of omission errors: $Z = -0.14$, $P = 0.888$) were also not significant and represented only small to negligible effects. The small but nonsignificant effect sizes point to an improvement of functioning with the exception of the difference in tonic alertness (reaction time).

Comparisons of ipsative scores between ADHD groups

The results of the comparison between the two ADHD groups regarding the ipsative scores reflect the findings of

Table 4 Effect sizes for group differences (neuropsychological test measures)

	Children with ADHD	
	Attention training group Pre-training performance versus post-training performance	Perception training group Pre-training performance versus post-training performance
Tonic alertness		
Reaction time (ms)	0.22	0.46
Number of omission errors	0.18	–
Phasic alertness		
Reaction time (ms)	0.14	0.29
Number of omission errors	0.0	–
Vigilance		
Reaction time (ms)	0.16	0.30
Number of omission errors	0.32	0.36
Number of commission errors	0.59	0.02
Selective attention		
Reaction time (ms)	0.09	0.69
Number of omission errors	0.54	0.16
Number of commission errors	0.32	0.66
Divided attention		
Reaction time (ms)	0.16	0.24
Number of omission errors	0.04	0.23
Number of commission errors	1.28	0.0
Flexibility		
Reaction time (ms)	0.59	0.38
Number of commission errors	0.84	0.40

the analysis of the pre- and post-training assessments. Significant differences between the two ADHD groups were found in the number of commission errors in both the vigilance task ($Z = -1.99$, $P = 0.047$) and the divided attention task ($Z = -2.47$, $P = 0.014$). These differences represented medium to large effects (Table 5). The two groups did not differ significantly in the remaining measures of tonic alertness (reaction time: $Z = -0.26$, $P = 0.809$; number of omission errors: $Z = 0.00$, $P = 1.000$), phasic alertness (reaction time: $Z = -0.19$, $P = 0.867$; number of omission errors: $Z = -0.42$, $P = 0.809$), vigilance (reaction time: $Z = -0.45$, $P = 0.669$; number of omission errors: $Z = -1.15$, $P = 0.254$), selective attention (reaction time: $Z = -0.57$, $P = 0.590$; number of omission errors: $Z = -2.00$, $P = 0.051$; and number of commission errors: $Z = -1.28$, $P = 0.239$), divided attention (reaction time: $Z = -0.15$, $P = 0.897$; number of omission errors: $Z = -0.29$, $P = 0.780$), and flexibility (reaction time: $Z = -0.23$, $P = 0.838$; number of commission errors: $Z = -0.43$, $P = 0.669$). These differences were of medium, small or negligible size. With the exception of a small and nonsignificant effect (reaction time in the visual scanning task) showing a more pronounced improvement of children who participated in the visual perception training, all significant and nonsignificant differences of small to large size indicated that the attention training was more effective than the visual perception training.

Comparisons among ADHD groups following intervention (attention training, visual perception training) and the healthy control group

Alertness

Statistical analysis following completion of the interventions showed that groups did not differ with regard to tonic alertness (reaction time: $\chi^2 = 0.57$, $df = 2$, $P = 0.753$; number of omission errors: $\chi^2 = 1.69$, $df = 2$, $P = 0.430$) or phasic alertness (reaction time: $\chi^2 = 2.28$, $df = 2$, $P = 0.319$; number of omission errors: $\chi^2 = 4.09$, $df = 2$, $P = 0.130$).

Vigilance

Kruskal–Wallis tests indicated that the three groups differed significantly in both the number of omission errors ($\chi^2 = 10.36$, $df = 2$, $P = 0.006$) and commission errors ($\chi^2 = 7.50$, $df = 2$, $P = 0.024$), but not in reaction time ($\chi^2 = 4.16$, $df = 2$, $P = 0.125$). These results are

Table 5 Ipsative scores for children with ADHD (mean ± SEM)

	Children with ADHD		Effect sizes (d)
	Attention training group	Perception training group	
Tonic alertness			
Reaction time (ms)	−10.5 ± 12.3	−13.9 ± 11.3	0.06
Number of omission errors	−0.06 ± 0.14	0.00 ± 0.00	0.14
Phasic alertness			
Reaction time (ms)	−3.7 ± 6.8	−6.3 ± 7.2	0.08
Number of omission errors	0.0 ± 0.13	0.06 ± 0.06	0.17
Vigilance			
Reaction time (ms)	26.3 ± 75.1	−29.7 ± 40.5	0.23
Number of omission errors	0.88 ± 0.94	−1.06 ± 1.09	0.49
Number of commission errors	7.50 ± 3.53	−0.13 ± 2.13 *	0.66
Selective attention			
Reaction time (ms)	129.6 ± 530.5	780.3 ± 416.1	0.34
Number of omission errors	1.50 ± 0.94	−0.31 ± 0.95	0.47
Number of commission errors	0.56 ± 0.68	−0.50 ± 0.27	0.53
Divided attention			
Reaction time (ms)	−13.2 ± 31.2	−23.6 ± 38.1	0.08
Number of omission errors	−0.13 ± 0.88	−0.50 ± 0.74	0.11
Number of commission errors	2.31 ± 0.82	0.00 ± 0.40 *	0.89
Flexibility			
Reaction time (ms)	56.4 ± 38.5	65.6 ± 55.6	0.05
Number of commission errors	2.75 ± 1.31	2.44 ± 2.34	0.05

* $P < 0.05$ (Mann–Whitney–U test)

comparable with the findings of the comparison of groups prior to intervention. Further analysis, however, indicated that children of the attention training group did not differ significantly from healthy children any more (number of omission errors: $Z = -1.73$, $P = 0.086$; number of commission errors: $Z = -0.44$, $P = 0.669$). In contrast, children of the perception training group still presented an increased number of both omission errors ($Z = -3.24$, $P = 0.001$) and commission errors ($Z = -2.90$, $P = 0.003$) relative to healthy children. Despite these differences, no significant differences were found between the two ADHD groups (number of omission errors: $Z = -1.40$, $P = 0.171$; number of commission errors: $Z = -1.65$, $P = 0.102$).

Selective attention

A significant difference was observed among groups in the number of omission errors ($\chi^2 = 8.12$, $df = 2$, $P = 0.017$). Groups did not differ in reaction time ($\chi^2 = 3.16$, $df = 2$, $P = 0.206$) and the number of commission errors ($\chi^2 = 1.24$, $df = 2$, $P = 0.539$). Post hoc analysis revealed that children of the perception training group made significantly more omission errors than healthy children ($Z = -2.94$, $P = 0.003$). Children of the attention training group did not differ from both healthy children ($Z = -0.23$, $P = 0.838$) or children in the perception training group ($Z = -1.90$, $P = 0.061$).

Divided attention

Significant differences among groups were found in the number of both omission errors ($\chi^2 = 15.16$, $df = 2$, $P = 0.001$) and commission errors ($\chi^2 = 12.08$, $df = 2$, $P = 0.002$). The difference in the reaction time was not significant ($\chi^2 = 0.69$, $df = 2$, $P = 0.708$). Further analysis showed that children of the perception group displayed a significantly higher number of commission errors than both healthy children ($Z = -2.88$, $P = 0.004$) and children of the attention training group ($Z = -3.02$, $P = 0.003$). Furthermore, children with ADHD made significantly more omission errors than healthy children (attention training group: $Z = -2.22$, $P = 0.032$; perception training group: $Z = -4.01$, $P < 0.001$). The comparisons between children of the attention training group and healthy children in the number of commission errors ($Z = -0.29$, $P = 0.809$) and between the two ADHD groups in the number of omission errors ($Z = -1.33$, $P = 0.196$) did not reach significance.

Flexibility

The results of this data analysis are similar to the findings of the analysis prior to intervention. The three groups differed significantly in the number of commission errors ($\chi^2 = 6.29$, $df = 2$, $P = 0.043$) but not in reaction time

($\chi^2 = 0.86$, $df = 2$, $P = 0.650$). The ADHD groups did not differ in the number of commission errors ($Z = -0.32$, $P = 0.752$); however, both ADHD groups made significantly more commission errors than healthy children (attention training group: $Z = -2.11$, $P = 0.039$; perception training group: $Z = -2.21$, $P = 0.029$).

Discussion

Previous research demonstrated that children with ADHD suffer from various cognitive deficits despite successful pharmacological treatment (Gualtieri and Johnson 2008). For example, a study focusing on attention deficits of children with ADHD and the effects of stimulant drug treatment on these deficits showed that pharmacological treatment does not normalize attentional functioning in children with ADHD (Tucha et al. 2006b). These findings are confirmed by the present study. Children with ADHD prior to intervention displayed significant deficits of vigilance, selective attention, divided attention, and flexibility. The impairments of children with ADHD were reflected in poorer task accuracy as indicated by increased numbers of omission and commission errors. Therefore, children with ADHD on pharmacological treatment do not necessarily reach an undisturbed level of attentional functioning. Consequently, additional treatment of the deficits should be considered, in particular, since attention represents a basic function for higher cognitive functioning and because persistent attention deficits are associated with poor social, academic, and occupational outcome (Manly and Robertson 2003).

One possible option for an additional treatment could be an increase in the total daily dosage of a particular drug or the use of a different, possibly more effective drug for the individual patient. However, these possibilities are limited because of side effects and the lack of alternative drugs in some countries. Furthermore, these issues are usually already taken into consideration by medical professionals who prescribe stimulant drug treatment. Another option could be the use of non-pharmacological treatments, which can be given in combination with a pharmacological treatment. Therefore, a computerized training of attention functions was applied in the present study. Previous studies already demonstrated that attention trainings can be effective in children with ADHD (Kerns et al. 1999; Semrud-Clikeman et al. 1999; Tamm et al. 2010). The present examination complements these studies by focusing more on the multi-dimensional concept of attention. Consequently, various attention functions were examined in the pre- and post-training assessment of children with ADHD. In the attention training, procedures for the specific training of vigilance, selective, and divided attention were selected.

Data analysis demonstrated that the training of attention functions in children with ADHD resulted in significant improvements of medium to large size regarding vigilance, divided attention and flexibility. In agreement with this finding, children of the attention training group displayed significant improvements of medium to large size in vigilance and divided attention when compared with children with ADHD who participated in the visual perception training. In this context, it appears noteworthy that there was also a number of additional nonsignificant improvements in the attention training group. These improvements represented medium to small effects (e.g., in selective attention). Furthermore, despite the fact that the visual perception training neither explicitly nor specifically trained attention functions, children of this group were also required to concentrate on training materials for 45 min per session. Thus, one could assume that the visual perception training might also have a beneficial effect on attentional functioning, e.g., on selective attention (concentration). Therefore, since the perception training represents a conservative clinical control condition, the effects of the attention training might have been even larger when compared with a group of children with ADHD without any training. This might also be the reason why the improvement of flexibility found in the comparison between the pre- and post-assessment of the attention training group was not reflected in the comparison of the two ADHD groups (ipsative scores). An active clinical control group, i.e., a group that also received some kind of training, was chosen since the social interaction with or the attention from a therapist could have positive and motivating effects on the functioning of an individual, e.g., because of the personal appreciation people may experience (Niemann et al. 1990).

The present findings clearly indicate that the attentional functioning of children with ADHD benefits from a specific training of attention. These benefits were not only observed in the functions that were specifically trained (vigilance, selective attention, and divided attention) but also in an untrained function. Following the training, children of the attention training group displayed significant and nonsignificant improvements of medium to large size in flexibility, although this function was not trained. This indicates that there is a generalized effect of the training on attentional functioning. It is very unlikely that the improvements found in children of the attention training group resulted from the fact that the same test procedures were used in the pre- and post-assessment, because such practice effects were not found in children of the perception training group who also performed these tests twice. Furthermore, since participants were randomly assigned to groups and groups did not differ in attentional functioning prior to intervention, it can be excluded that the present findings resulted from a comparison of different populations. The assessments and interventions used in the present study were performed, while children were on medication. It is difficult to decide whether children with ADHD would have benefited more or less if the training had been performed while they were off medication. Both types of training required children to concentrate for 45 min. Although there was the possibility for children to have short breaks during this period, we believe on the basis of our experience with unmedicated children with ADHD that it would be extremely difficult for them to concentrate on the training procedures for the requested time period without medication. Consequently, their benefit would be reduced or even jeopardized. It appeared reasonable to measure the effect of the training procedures, while children were on medication, since the main aim of the present study was to assess whether attention training could add a verifiable effect to the effects of medication. A discontinuation of pharmacological treatment on the basis of an effective attention training was never considered because of the beneficial effects of medication on various aspects of children's functioning, such as social behavior, academic skills, and cognition (DuPaul et al. 1998).

The attention training used in the present study led to significant large and medium improvements of vigilance, divided attention, and flexibility. Furthermore, an improvement of selective attention was observed, which did not reach significance but was of medium size. One can therefore conclude that all components of attention, which have repeatedly been found to be impaired in children with ADHD (Tucha et al. 2006b) can be improved with specific training programs. Since these improvements were achieved after only 8 sessions of 45 min, it appears that such a training should routinely be performed in children with ADHD. However, there are a number of unsolved problems. First, children with ADHD did not reach an undisturbed level of attentional functioning. While their performance in alertness, vigilance, and selective attention following the training was similar to that of healthy children, they continued to display significant deficits with regard to divided attention and flexibility. It is unclear whether children could have benefited more from a different schedule, such as more training sessions, a different length of sessions or a different time period between sessions. Previous studies on the efficacy of attention trainings differed quite markedly in the time schedules and schemes they applied. These studies used individual or group trainings in sessions of 30–60 min, twice per week for periods between 8 and 16 weeks (Kerns et al. 1999; Semrud-Clikeman et al. 1999; Tamm et al. 2010). Similar to the present study, previous studies also reported effects that were up to large size. This may indicate that attentional functioning of children with ADHD can be trained successfully with various schedules and training programs. However, no conclusion can be drawn from these studies concerning an additional benefit of a more extensive training, since the only study that also examined a group of healthy participants focussed primarily on sustained attention (Semrud-Clikeman et al. 1999). As with the present findings in vigilance performance, the authors found no differences between children with ADHD and healthy children in sustained visual and auditory attention after completion of their attention training.

A second problem is that it is not clear what an improvement of test scores in neuropsychological test measures as used in the present and previous studies means in real life. This problem refers to the question of ecological validity of assessment and the external validity of results. Laboratory tests of attention have been used in studies, since they allow for an inexpensive, quick but also objective examination of the effects of behavioral interventions (Lezak et al. 2004). However, these tests often lack ecological validity, i.e., the functional and predictive relationship between participants' task performance and their normal behavior (Sbordone and Long 1998). Kerns et al. (1999) and Tamm et al. (2010) performed behavioral rating questionnaires for teachers, clinicians, and/or parents beside neuropsychological measures. While Kerns et al. (1999) found no significant treatment effects, Tamm et al. (2010) observed that parents and clinicians reported significantly fewer ADHD symptoms in children with ADHD following completion of an attention training. However, it is not clear whether the reduction in symptoms and the improvements of attentional functioning measured in the laboratory have any impact on the children's everyday life, such as an improvement of academic performance or social behavior. To find evidence for improvements in everyday life, future research has to incorporate a measurement of everyday functioning, such as observations of classroom behavior, assessments of learning efficacy, and recordings of school grades.

A further difficulty is that there is only little evidence to assume that an attention training has lasting effects on children's attention. The majority of studies, including the present study, did not perform a neuropsychological assessment later than immediately after completion of the training. However, Tamm et al. (2010) performed a follow-up assessment via telephone on a small sample ($n = 9$), 9 months after completion of the "Pay Attention!" program. The follow-up evaluation revealed that according to parents' reports, children maintained their benefit from the training in terms of ADHD symptomatology. Although this provides an indication of the potential of attention training in the treatment of children with ADHD, there is a need of further research which incorporates objective measures of attention and everyday functioning.

Fourth, current evidence on the effectiveness of attention trainings in children with ADHD are based on a small number of studies with small sample sizes. The reason for this is that studies on the effectiveness of behavioral training are complex, expensive, and time consuming. Attention trainings require the availability of personnel for prolonged periods of time. Furthermore, the regular participation of patients is essential. However, regular attendance appears to be particularly difficult for patients with ADHD and their families because of motivational issues or poor organizational skills of patients. A good example for that is the study of Tamm et al. (2010). From their 29 recruited participants, 23 were finally included in the study. The attendance of these participants ranged between 4 and 16 sessions. A number of children did not participate in the outcome evaluation had consecutive absences or participated in alternative treatments (e.g., neurofeedback). Finally, only 7 children participated in all 16 sessions of the training program and only 9 children underwent follow-up evaluation 9 months after the intervention.

In conclusion, the findings of the present study support the results of previous studies, which found that attention training programs have the potential to facilitate attentional functioning in children with ADHD. Training programs with as few as 8 h contact time have been shown to have positive effects on performance on laboratory measures of attention. Provided that these positive effects have a lasting impact on important areas of daily functioning of children with ADHD, neuropsychological training programs of attention may be an effective, promising and inexpensive form of non-pharmacological treatment, which can be performed alongside medication use. However, current knowledge about the impact of attention training on everyday life performance of children with ADHD is limited. It is therefore possible that the kind of training provided is ineffective or only transiently effective regarding particular environments or situations for which clinicians, parents, and children seek support (e.g., paying attention in classroom courses). In that case, the implementation of attention training programs would be an expensive endeavor. The aim of future research should therefore be the follow-up assessment of the effects of attention trainings or other cognitive training programs on everyday functioning of children with ADHD. Further research in this field should also assess whether cognitive training may be effective alone, i.e., without associated pharmacological treatment. The present results must be viewed in the context of some limitations: Only small sample sizes were examined. Therefore, statistical power should be considered. The power to detect medium effects in attention between the pre-training performance and the post-training performance was less than 30% for each group. Furthermore, a substantial number of children with ADHD had a comorbid psychiatric disorder, which increases heterogeneity and reduces generalizations of conclusions of the present study. Moreover, different tests were used for the assessment of intellectual functioning (IQ), which might bear the risk of an increased heterogeneity among samples. In addition, no statistical corrections (e.g., Bonferroni correction) required by multiple comparisons within the study were performed. This strategy increases the likelihood of type I errors. Finally, the two trainings compared in this study differed in the way materials were presented. While the attention training comprised of computerized tasks, the perception training was not computerized. Therefore, we cannot rule out that the improvements found in the group performing the attention training did not result from nonspecific effects of using a computer. However, the attention training program used in the present study is not comparable to current computer games regarding graphics, sound, and complexity. Since these computer games are widely distributed among children, we believe that the attraction of the novelty of the attention training program used in this study should not be overestimated.

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